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Performance Tests of Mn-Added Aluminum Heat Pipe with Micro-sized Inner Fins and Thermal Fluid for Cooling Electronic Device[1]

M. R. Kim and Y. Choi

Department of Materials Science and Engineering, Dankook University, Cheonan, 330-714 Republic of Korea

e-mail: yochoi@dankook.ac.kr

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Abstract—Aluminum–5 wt % manganese alloy heat pipe with a nano-fluid of n-butanol and 0.2 wt % carbon nano-tubes was prepared by deep-drawing, and its mechanical and corrosion properties were determined to improve thermal conductivity performance. The heat pipe was designed to have micro-sized inner fins working at temperature higher than 200°C and simultaneously retaining a similar thermal conductivity to that of pure aluminum. The heat pipe formed by aluminum–5 wt % manganese alloys had improved mechanical properties such as 38% micro-hardness, 45.8% yield strength, and 53.5 wt % ultimate tensile strength due to grain size refinement and work hardening effects. The corrosion rate of the aluminum alloy in artificial sea water at room temperature decreased from 0.110 mpy to 0.102 mpy. The nano-fluid of n-butanol and 0.2 wt % carbon nano-tubes improved the thermal conductivity of the heat-pipe by about 250%.

Keywords: aluminum manganese alloy heat pipe, thermal conductivity, mechanical properties

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INTRODUCTION

A heat pipe is a heat transfer medium that uses the phase transformation of a working fluid inside a metallic pipe. It is usually made with consideration for the service temperature and temperature range [1]. The main body of the heat pipe is made of a metal with high heat conductivity like pure aluminum. Recently, the use of thermal fluid with nano-particles inside the heat-pipe has attracted attention for the enhancement of the heat transfer effect [2–4]. Although the pure aluminum is suitable for the heat pipe body because of its light weight, affordability, and high thermal conductivity, the thin aluminum heat-pipe is relatively soft and plastically deformed by the thermal expansion of the working fluid due to long exposure to temperatures above 200°C. Accordingly, it is necessary to improve the strength of the base metal for various applications [5]. Although there are many aluminum alloys such as 2xxx, 6xxx and 7xxx, most alloy elements except manganese tend to significantly decrease the thermal conductivity of the aluminum alloys [5–8]. Hence, the objectives of this study are to find an aluminum alloy with improved mechanical and corrosion properties with micro-sized inner fins and to carry out performance tests of the thermal fluid for cooling an electronic device. Emphasis is placed on the effects of the nano-fluid on the thermal conductivity and the mechanical and corrosion properties of the aluminum–5 wt % manganese heat pipe.

[1] The article is published in the original.

EXPERIMENTAL METHOD

1. Fabrication of a Heat Pipe

Two kinds of materials were used to make the material of the heat pipe. One is pure aluminum (AA-1002) and the other is aluminum–5 wt % manganese alloy. The heat pipe with micro-sized fins inside was fabricated by deep-drawing. Figure 1 is a schematic diagram of the cross section of the heat pipe. N-butanol with 0.2 wt % carbon nano-tubes was injected inside of the heat pipe followed by the mechanical sealing of both ends.

2. Microstructure Observation and Phase Identification

The microstructure of the deep-drawn Al–5 wt % Mn alloys was observed by scanning electron microscopy (Jeol, JSM6400, Japan). The etchant for the SEM observation was 13% NaOH solution. A phase analysis was carried out by X-ray diffractometry (Rigaku, UltimaIV, Japan) and energy-dispersive spectroscopy (Philips, EDX-XL30FEG, Netherlands).

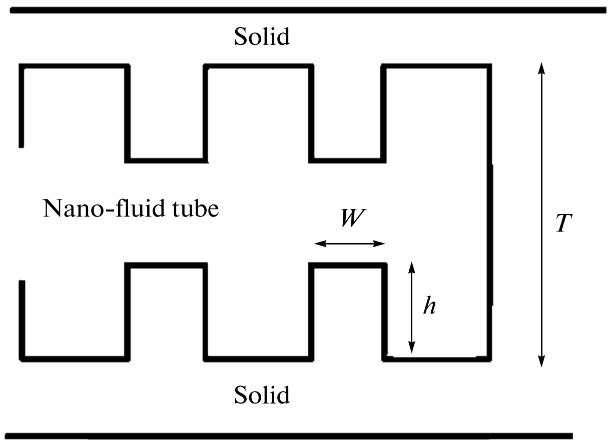

Fig. 1. Schematic diagram of cross section of the heat pipe: $h = 0.25$, $w = 0.2$, $T = 2$ mm.

3. Mechanical and Corrosion Tests

Mechanical tests of the deep-drawn Al–5 wt % Mn alloy and pure aluminum were performed with a universal tensile test machine (Instron–5900, USA) and micro-hardness tester (Micro-Vickers, USA). A corrosion test of the deep-drawn Al–5wt % Mn alloy was performed by an electrochemical method (Gamry 100, USA) in artificial sea water.

4. Thermal Conductivity Measurement

The thermal conductivity of the heat pipe with and without a nano-fluid of *n*-butanol and 0.2 wt % carbon nano-tubes was measured by a multi-thermocouple method. Fine K-type thermocouples were attached on the surface of the heat pipe to measure local temperature changes. The heat pipe was vertically installed in an insulated cabinet. A heat source was located at the bottom of the cabinet. The temperature variation of each point of the heat pipe was determined with a signal analyzer (Agilent Technologies, U2802A, USA).

RESULTS AND DISCUSSION

1. Microstructure Observation and Phase Identification

Figure 1 shows the microstructure of the matrix of the heat pipe normal to the rolling direction observed by scanning electron microscopy. The average grain sizes of the pure aluminum and the Al–5 wt % Mn alloy of the heat pipes are about 167.5 and 58.0 μm, respectively. Table 1 shows the EDX results, which support that the matrix of the heat pipe is Al–5%Mn alloy. Figure 3 shows X-ray spectra of the matrix of the heat pipe and pure aluminum powders. The matrix of the heat pipe is crystalline (*Fm*3*m*) with a lattice parameter of 0.40498 nm. This is slightly greater than the lattice parameter of pure aluminum of 0.40494 nm, which is related to the solid solution of 5 wt % manganese of the matrix of the heat pipe. Compared to the X-ray spectra of pure aluminum powders, the spectra of the matrix of the heat pipe show the strongest (311) peak, which means that it has a preferred orientation due to deep-drawing.

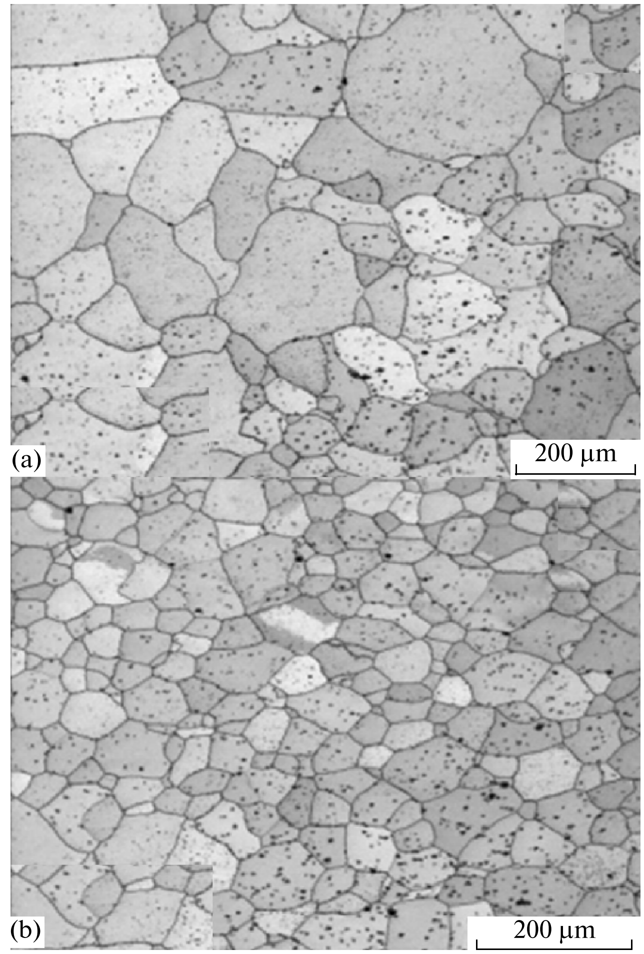

Fig. 2. Microstructure of (a) pure aluminum, (b) Al–5 wt % Mn alloy.

Mechanical properties of heat pipes

	UTS, MPa	Y.S, MPa	E_f, %	Hard., Hv
Aluminum	45.6	36.0	48.0	121.5
Al–5 wt %Mn	70.0	52.5	47.0	168.0

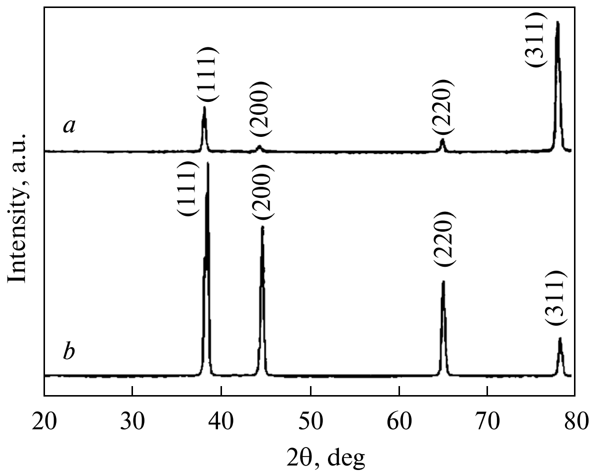

Fig. 3. X-ray spectra of matrix material (a) aluminum powder, (b) deep-drawn Al–5 wt % Mn alloy for heat pipe.

2. Mechanical Properties

Table 2 shows the mechanical properties of the pure aluminum and Al–5 wt % Mn alloy heat pipes. The ultimate strength (UTS), yield strength (YS), elongation, and micro-hardness of the pure aluminum heat pipe are 45.6 MPa, 36.0 MPa, 48%, and 121.5 Hv, whereas, those of the Al–5 wt % Mn heat pipe are 70.0 MPa, 52.5 MPa, 47.0%, and 168.0 Hv, respectively.

The strength of the deep-drawn alloys depends on the grain size and the concentration of solid solution described by the Hall-Petch equation. In Fig. 3 and Table 2, the improved strength of the Al–5 wt % Mn alloy heat pipe is related to grain size refinement and solid solution hardening. The former can contribute to increasing the strength by about 14%, whereas the latter corresponds to about 4% based on the Hall-Petch relations.

3. Corrosion Properties

Figure 4 shows typical polarization curves of the aluminum alloy in aerated artificial sea water. As shown in Fig. 4, there is no passivity. The corrosion potential and corrosion rate of the pure aluminum and Al–5wt % Mn alloy of the heat pipes were –1.7 V_{SHE}, 2.1×10^{-6} A/cm^2 and –1.6 V_{SHE}, 2.3×10^{-6} A/cm^2, respectively. These corrosion rates corresponded to 0.107 mpy for pure aluminum and 0.110 mpy for Al–5 wt % Mn alloy heat pipes. It means that 5 wt % Mn addition improves corrosion resistance by about 8% in this test condition.

4. Thermal Conductivity Behaviors

Figure 5 shows the thermal conductivity of Al–5 wt % Mn alloy heat pipes containing nano-fluid over time when a heat source of 100°C is located at the origin point of the distance. The temperature was determined at every 20-cm interval from the heat source.

As shown is Fig. 5, the time to reach 90°C at the 20-cm point from the origin point is shorter for the heat-pipe with nano-fluid than that without nano-fluid. This supports that the nano-fluid works effectively to improve the thermal conductivity of the heat pipe. Since the thermal conductivity of the pure aluminum is about 234 W/m °C, the thermal conductivity was improved by the nano-fluid. It is more than 250% improvement. It supports that the heat pipe with nano-fluid will be applicable to various engineering parts working in severe thermal environment.

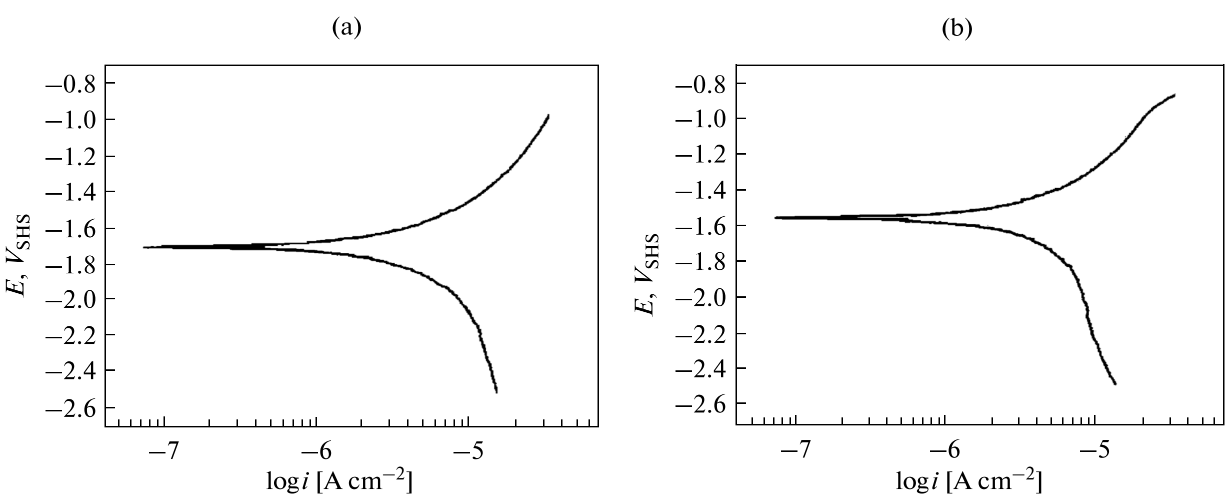

Fig. 4. Polarization curve of (a) pure aluminum, (b) aluminum alloy.

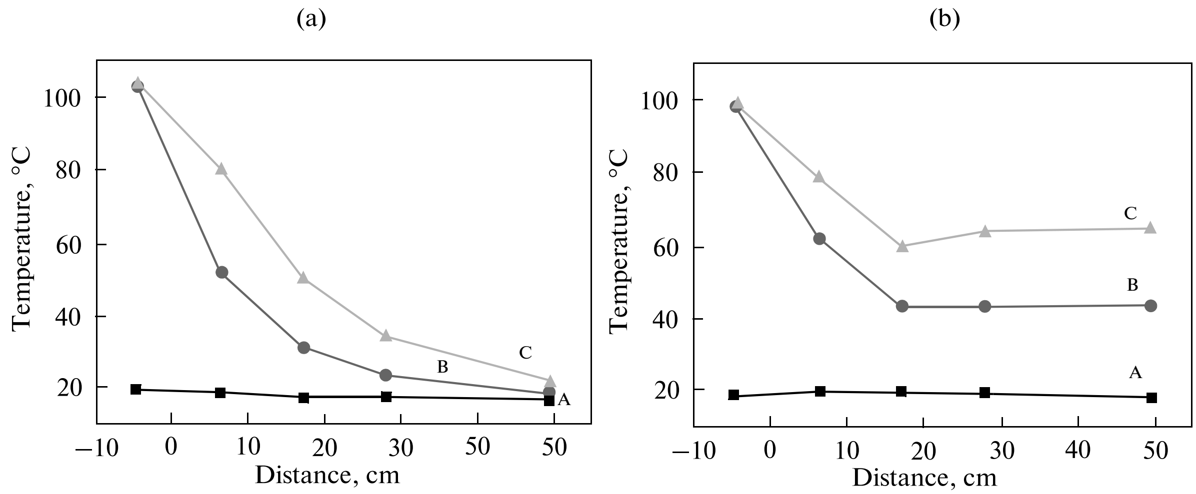

Fig. 5. Effect of nano-fluid on the thermal conductivity of Al–5% Mn of heat pipe with time interval (A: 30 s, B: 60 s, C: 90 s) (a) without nano-fluid, (b) with nano-fluid.

CONCLUSIONS

In order to improve the thermal conductivity and mechanical properties of a pure aluminum heat pipe, an Al–5 wt % Mn alloy heat-pipe containing a nano-fluid of n-butanol and 0.2 wt % carbon nano-tubes was prepared by deep-drawing. The results are summarized as follows:

(1) The deep-drawn Al–5 wt % Mn had a preferred orientation. The ultimate strength (UTS), yield strength (YS), elongation, and micro-hardness of the pure aluminum heat pipe were 45.6 MPa, 36.0 MPa, 48%, and 121.5 Hv, whereas, those of the Al–5% Mn heat pipe were 70.0 MPa, 52.5 MPa, 47.0%, and 168.0 Hv, respectively.

(2) The corrosion potential and corrosion rate of the pure aluminum and Al–5 wt % Mn alloys of the heat pipes were –1.7 V_{SHE}, 2.1×10^{-6} A/cm^2, and –1.6 V_{SHE} 2.3×10^{-6} A/cm^2, respectively.

(3) The nano-fluid in the Al–5 wt % Mn alloy heat pipe effectively improved its thermal conductivity by more than 250%.

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